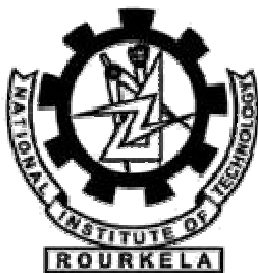


# **MODELLING OF DOUBLY FED INDUCTION GENERATOR CONNECTED WITH A WIND TURBINE**

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# **MODELLING OF DOUBLE FED INDUCTION GENERATOR CONNECTED WITH WIND TURBINE**

*A Thesis submitted in partial fulfillment of the requirements for the degree of*

*Bachelor of Technology in “Electrical Engineering”*

By

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May, 2014



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## CERTIFICATE

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This is to certify that the thesis entitled "**Modelling of Doubly Fed Induction Generator Based Wind Turbine**", submitted by **GANESH KUMAR SUMAN (Roll. No. 110EE0446)** and **SUCHIT KUMAR SETHI (110EE0229)** in partial fulfilment of the requirements for the award of **Bachelor of Technology** in **Electrical Engineering** during session 2013-2014 at National Institute of Technology, Rourkela. A bona fide record of research work carried out by them under my supervision and guidance.

The candidates have fulfilled all the prescribed requirements.

The Thesis which is based on candidates' own work, have not submitted elsewhere for a degree/diploma.

In my opinion, the thesis is of standard required for the award of a bachelor of technology degree in Electrical Engineering.

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## **ABSTRACT**

There has been a tremendous rise in the use of the renewable energy resources. Global wind energy capacity soared by a fifth to 238GW at the end of 2011. India is the 5th largest player globally, accounted for 16 GW. Wind energy is an important form of renewable energy as there is no greenhouse gas emission compared to non-renewable fossil fuels. There has been a rising demand for wind energy ever since its first implementation.

This project work studies the power-speed characteristics and the torque-speed characteristics and the fundamentals of wind electrical systems along with the modeling of the various wind turbine features and simulation of the same using MATLAB-SIMULINK. This paper develops a simple

DFIG wind turbine model . This paper deals in conversion theory of (d – q) model . By using the equations of d-q model, dfig equations are simulated in matlab Simulink .

## **ACKNOWLEDGEMENT**

I have been very fortunate in having Professor Bidyadhar Subudhi, branch of Electrical Engineering, NIT, Rourkela as my thesis supervisor. He inspired me to develop interest in Wind Energy Systems, taught me essence and principle of research and guided me through the completion of this thesis work. Working with Prof. Bidyadhar Subudhi is highly enjoyable, inspiring and learning experience. I am indebted to him and express my deep sense of gratitude for his guidance and support. I am highly indebted to the authorities of NIT, Rourkela for providing me various facilities like library, computers and Internet, which have been very useful. I express special thanks to all my friends, for being there whenever I needed them. I dedicate this thesis to my family and friends.

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## **CHAPTER I: INTRODUCTION**

### **1.1 Motivation;**

This known to all that the burning of fossil fuels are having a vital influence on the global climatic conditions . Effective changes in the climatic condition will require deep reduction in the emission of green house gases . The electricity systems are viewed as more easier to transfer to low carbon energy source than most of the challenging sectors of a economy such as surface and air transport . Hence the significant use of cost-effective and reliable low carbon electricity generation sources, in addition to demand-side measures are becoming the most important objective of energy policies in many countries. Over the past decades, wind energy has been accounted for the fastest rate of growth among any form of electricity generation with its development stimulated by concerns over the climatic changes, energy diversities and security of supply by many policy makers. The maximum energy that can be taken out from the 0-100 meters layer of the atmosphere has been approximated to be around  $10^{12}$  kWh per year , which is having the same potential as hydro-electric generation .

### **Advantages of using wind energy:**

1. it is a clean source of energy .no emission of green house gas so no problem of ozone layer depletion .
2. it can be harnessed easily and having its availability in abundance .
3. it is simply a different form of solar energy which is caused by the non uniform heating of earth surface and revolution of earth .
4. it's price is very less costing around 3-4 cents kwh so it will also help in developing the rural area where wind is available in abundance by making wind mills in farm and ranches .

## 1.2 Relevant Terms:

**Power Contained in the Wind:** This is the same as that of the kinetic energy of the flowing air masses per unit of time is given by

$$P_0 = \frac{1}{2}(\rho A V_\infty^2)(V_\infty)$$
$$\Rightarrow P_0 = \frac{1}{2}(\rho A V_\infty^3)$$

### Betz limit:

It gives the maximum energy that can be extracted from the flowing wind and is given by

$$P_{max} = \frac{16}{27}P_0 = \frac{8}{27}\rho A V_\infty^3$$

### Tip Speed Ratio:

Tip speed ratio (TSR) of any wind turbine is called as

$$\lambda = \frac{2\pi R N}{V_\infty}$$

## 1.3 Various Types of Wind Turbine:

### 1.3.1 Horizontal Axis Wind Turbine (HAWT):

A horizontal axis wind turbine has its blades rotating on an axis which is parallel to the ground. It is the most common type of wind turbine.

### **Advantages of HAWT:**

Variable blade pitches provides the suitable angle of attack and greater control along with good efficiency. It is located on taller towers therefore subjected to some greater wind speeds. Usually a 10m increase in the height of a tower provide 20% increment in wind speed. Since the blade moves at an angle complementary to that of the wind speed therefore drag forces are greatly reduced which causes increment in the power output.

### **Disadvantages of HAWT:**

Greater construction costs for the larger structures . Also the transportation cost increases significantly. Production of noises affect the radar operations. Great wind speed and turbulences may lead to that of structural failure. Additional Yaw Controlled mechanisms are required.

Horizontal axis wind turbines are further classified into:

- A) "Dutch-type" grain grinding windmill:
- B) Multi blade Water Pumping windmill:
- C) High Speed Propeller type Wind Turbine

### **1.3.2. Vertical Axis Wind Turbines (VAWT):**

A VAWTS have its blades rotating on the axes perpendicular to that of the ground. It is not used widely for the commercial purposes compared to that of the HAWT.

### **Advantages of VAWT:**

Mounted close to the ground so tall structures are not required. It is having less cost and easier maintenance, lower start up speed and very lower noise. Yaw control mechanisms are not required.



### **Disadvantages of VAWT:**

It has lower efficiency due to that of the additional drag forces, due to lower height they can't capture great wind speed at the higher altitudes, generally they need some additional start up mechanism as they are having zero starting torque.

Types of VAWT:

A) Savonius Wind Turbine

B.) Darrieus Wind Turbine

## **1.4 CONTROL METHODS FOR WIND TURBINE**

### **1.4.1. Terms related to Aero-foil Dynamics:**

Pitch Angle - Angle between that of aero-foil chord and plane of rotation.

Angle of inclination- Angle between the relative velocity vector and the plane of rotation.

Angle of incidence (attack) - Angle between the relative velocity and the chord line.

Drag Force- Force along the direction of the relative wind velocity.

Lift Force- Force normal to that of relative wind velocity.

Thrust Force- Component of total force along the wind velocity.

Torque Force- Component of the total force along the aerofoil velocity.

### 1.4.2 Types of control in wind turbine:

a) **Pitch Control**: Angle between the rotation plane and the turbine blade is varied. It depends on that of wind speeds, rotor speeds and power output. Blade is turned out when the power is very high, they are turned in when the power is very low. It is a relatively fast method and can be used for limiting the rotor speed by regulating the input aerodynamic flow of power, it is having a good power control, a assisted start up and a emergency stop. Unlike that of the stall control it need not to be shut down beyond some certain speed. Efficiency decrease at high wind speed as the pitch angle increases to drop some power.

b) **Stall Control**: It is one of the simple, cheap, and robust and it's inherent aerodynamic properties of the rotor blades help in determination the output power. These aerodynamically designed blade help the rotor in stalling (losing power) process .It is used for constant speed wind turbine. As the wind speed increase the lift force decreases and drag force increases. It is noisy, very sensitive to particles on the blade and initial blade angle and has a lower efficiency compared to that of the pitch control, even for rated speeds.

c) **Active Stall**: Combination of both pitch control and passive stall control. These blades are pitched similar to the pitch controlled turbine for low and medium speeds. Unlike that of a passive stall there is no drop in the power at higher speed as the blade is rotated by few degrees in the opposite direction compared to that of pitch controlled.

## CHAPTER II LITRETURE REVIEW

### 2.1 OUTLINE:-

In this section, the characteristics of wind pertinent to energy conversion will be presented; followed by an introduction to wind energy conversion systems. The equations governing such systems, their components and performance characteristics will be described in detail.

### 2.2 WIND ENERGY:-

The natural motion of air in the atmosphere, wind, is caused by pressure differences across the surface of the earth do to the uneven heating via solar radiation. From studies of fluid mechanics, this flow of air can be analyzed as mass flow with kinetic energy given by:

$$\frac{dm}{dt} = \rho AU \quad (1)$$

$$E = \frac{1}{2} mU^2 \quad (2)$$

$$P = \frac{1}{2} \rho AU^3 \quad (3)$$

Where “A” is the area of the incident air stream, U and  $\rho$  the velocity and density of the flow respectively. Generally, “A”, the stream area of interest is taken as the area swept by the rotor of a wind energy conversion system (WECS). Such systems convert the linear momentum of the air stream into a rotation of the WECS’ rotor, with a maximum possible efficiency of 59.26%, referred to as Betz limit. Furthermore, it can be observed from above equations that the available power in the wind increases at the cube of the air velocity, and from a substitution of “A” for the area of disk:

$$P = \frac{1}{2} \rho \pi R^2 U^3 \quad (4)$$

## **2.3 WIND ENERGY CONVERSION SYSTEM**

To date, there have been a variety of WECS' designs; however by far the most popular and widely used is the horizontal axis wind turbine (HAWT). As made clear in the Introduction, the design of interest is the low-cost, low-power HAWT design common in rural and urban applications. Such systems are becoming increasingly popular and consist of following 4 main components:-

### **Rotor assembly**

This consists of the blades of the turbine, along with the hub; upon which the blades are mounted. The performance of a wind turbine is greatly affected by blade geometry, and in many designs, this component is also the most expensive part of the turbine unit.

### **Drive train**

Connecting the rotor to the generator is the drive train. In larger wind turbine systems, the drive train includes gearing to increase the speed of rotation from the rotor into the generator. Small turbines do not have this feature; the drive train for these systems is simply a connecting shaft.

### **Generator**

The generator converts the mechanical rotation of the drive train into electricity. Small turbine generators are commonly of the 3-phase, permanent magnet type; however other generator types have been used.

### **Controller**

To protect the system, in addition to converting the output of the generator to domestic voltages, a power electronic interface converter is necessary.

## 2.4 Performance of a turbine:-

As noted, the performance of a turbine is greatly affected by geometry. Characterizing this performance is commonly done with a  $C_p$ - curve; a plot of power coefficient to the tip speed ratio of the blades. The power coefficient  $C_p$  denotes the efficiency of the blades in extracting the power in the wind, whilst the tip speed ratio (TSR) is the ratio of the speed of the blade tips to the air stream. The relationship is found as follows:

$$C_P = \frac{P_T}{P} = \frac{2P_T}{\rho A U^3} \quad (5)$$

$$C_P = c(\lambda, \beta)$$

Thus,  $C_p$  is the fraction of power that is transferred from the wind to the turbine blades. As previously mentioned, the theoretical limit for this is approximately 59.3%.

$$Q = C_Q \frac{1}{2} \rho \pi R^3 U^2 \quad (6)$$

$$C_Q = \frac{C_P}{\lambda} \quad (7)$$

Where  $C_Q$  is the torque coefficient in Nm developed by the rotor.

$$\lambda = \frac{R * \omega}{U} \quad (8)$$

Here

$\lambda$  =tsr (tip speed ratio)

$\omega$ = speed of turbines revolution

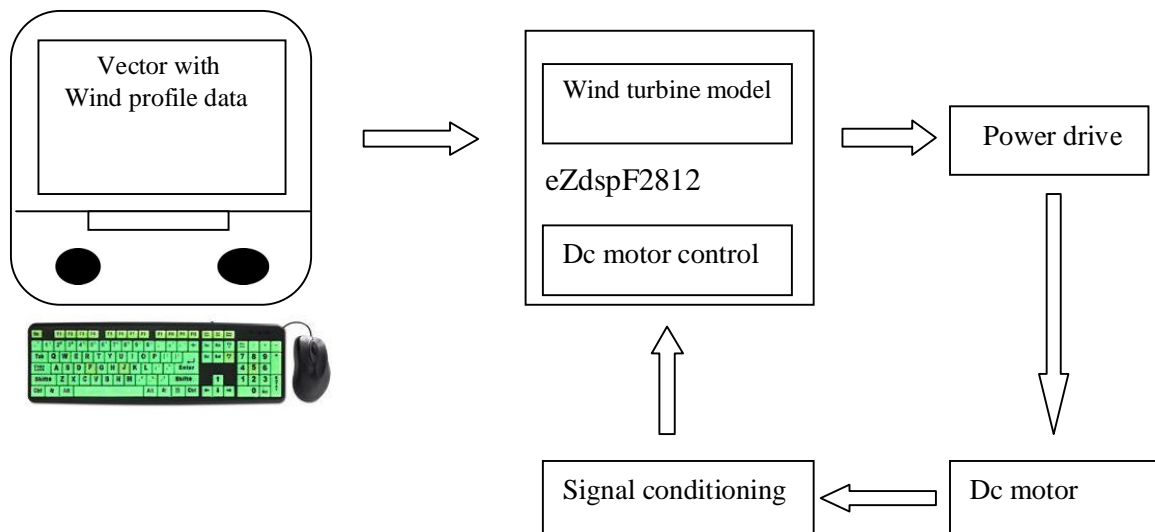
R = radius of the turbine

$\beta$  = pitch angle

$$P = \text{Blade Torque} \times 2\pi \times \text{RPM}/60 \quad (9)$$

## 2.5 wind turbine emulation:-

Among any machines dc motors are mostly used for the purpose of the emulation .here for emulation control system is used in the way it is shown in the figure inputs for these control purpose are speed and torque.motor current is used for the estimation of the motor torque . The input variable is introduced in a microprocessor that has kept the turbine curves and whose output is the reference torque for the DC motor.



**Fig (2.1) A wind turbine emulator**

## CHAPTER III INDUCTION GENERATOR

induction generator and asynchronous generators are type of A-C electrical generators that use the principle of an induction motor to produce power. these generators operate through mechanically rotating their rotor in that of the generator mode, having a negative slip. In many of the cases, a regular induction or A-C asynchronous motor is used as a generator, without doing any type of modification .

### 3.1 OPERATING PRINCIPLE

Induction generator produce electrical power when their rotor is made to rotate faster than that of synchronous frequency. Taking an example of a typical four-pole motor operating at a 60 Hz electrical grid, synchronous speed value is 1800 rotations per minute. Similarly four-pole motor operating at a 50 Hz grid will be having synchronous speed equal to that of 1500 rpm. In normal motoring operation, stator flux always rotates faster than that of rotor flux . This is setting up of stator flux to induce rotor current , which creates rotor flux with opposite magnetic polarity to that of stator. In this manner ,a rotor is behind the stator flux, by the value equal to that of the slip. In generator operations, a prime mover drives the rotor above that of the synchronous speed. The stator flux still induces electric currents into the rotor, but since the opposing rotor fluxes is now cutting the stator coils, active currents are produced in stator coils, and motor is now starts operating as a generator, and sends back the power to the electrical grids .

#### Grid and standalone connection:

In induction generator the magnetization flux is established by the capacitors banks connected with machine in case of the standalone system and in case of grid connected system, it draw magnetizing currents from the grid.

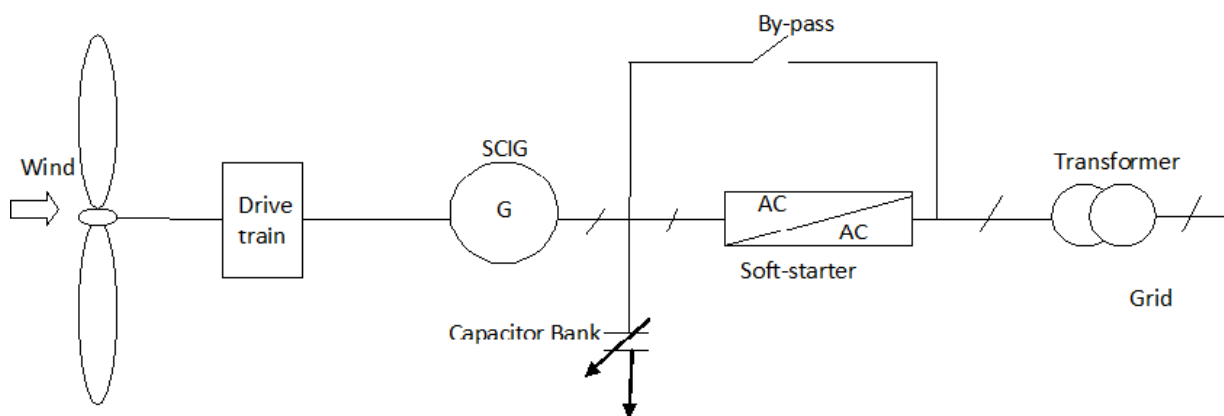
- For a system connected with grid , frequency and voltage of the machine is dictated by the electric grid since this is small in comparison with the whole system.
- For standalone systems , frequency and voltage form complex functions of machine parameters, capacitances used for excitation, and the load value and their type.

### 3.2 INDUCTION GENERATOR CONNECTED WITH GRID

Grid connected induction generator (dfig) develops their excitation from that of the grid. The generated power is fed into the supply system when the IG is made to run above that of the synchronous speed. Machines having cage type rotor feeds only through the stator part and mostly operates at low negative slips. But wound type rotor machine can feed power through the stator as well as rotor part to the bus over a wide range of speed and is known as Doubly Fed Induction Machine .

#### FIXED SPEED GRID CONNECTED WIND TURBINE GENERATOR:

The structures and performances of a fixed-speed wind turbines are shown in Figure given below which depends on the features of mechanical sub-circuits, like pitch control and time constants etc .



**Fig 3.1: squirrel cage IG connected to grid for fixed speed .**

The action time of circuits lie in range of the tens of a millisecond. As a result, every time when a gust of wind hits the turbine blade , a rapid variation in output power can always be observed. These variations for the generated electric power not only requires a firm power grid for enabling the stable operation, but also require a well-built mechanical designs which has the capability of absorbing high mechanical stresses, that leads to expensive mechanical structure, especially for highly rated electrical power.

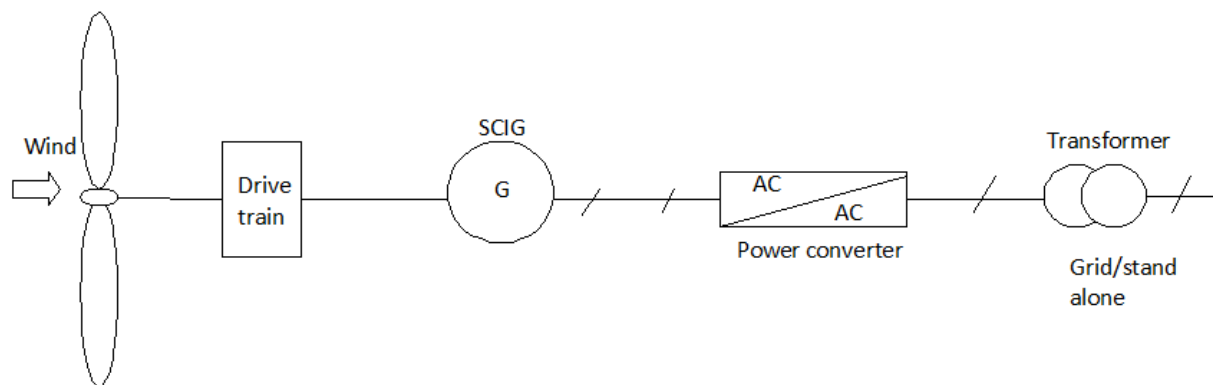


### Variable Speed Wind Turbine Generator:

More convenient turbines are variable speed turbines. Variable speed turbine has become one of the most dominating type wind turbines installed yearly as they can store the power fluctuations due to turbulence by increased rotor speed, pitched rotor blades, these turbine controls the power output at any of the given wind speeds.

Fig. 3.2 shows a variable speed turbine connected of a Squirrel Cage type Induction Generator SCIG. Although these direct online system has been built for 1.5 MW, but presence of power inverter causes a lot of disadvantages such as :-

- a) The power converters, which have to be rated at 1p.u. of total system power, is very expensive.
- b) Converters efficiency plays one of the most important role in determining total system efficiency over the entire operating range



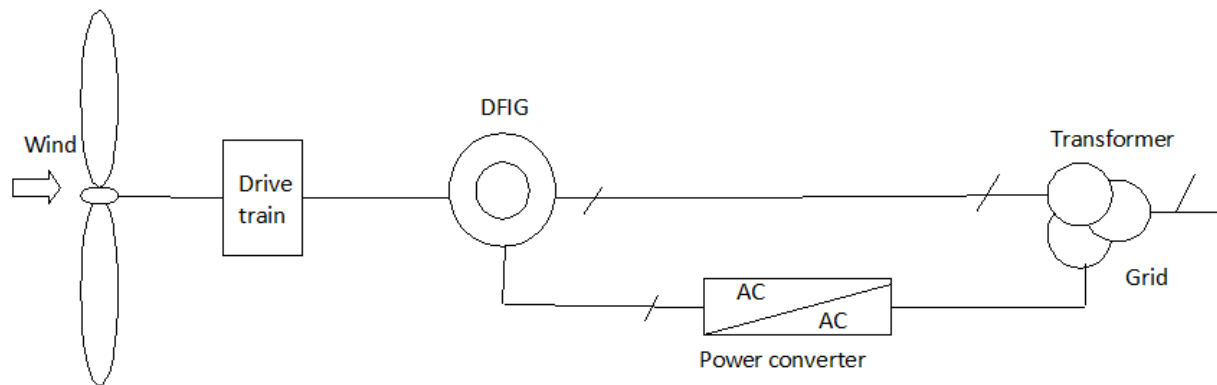
**Fig 3.2: variable speed wind turbine with squirrel-cage induction generator**

Other way is using of a Doubly Fed Induction Generator DFIG, as shown in Fig.3.3 It consists of a stator connected directly to the grid and a rotor through slip rings are

connected to the grid through four quadrants ac-to-ac converters based on insulated gate bipolar transistors .

This system has the following advantages:

1. Reduction in inverter cost, because inverter's rating is typically about 30% of total system power.
2. Improvement in the system efficiency.
3. implementation of power factor control strategy at lower cost.
4. It is having a complete control on the active and reactive power.



**Fig 3.3: Variable speed wind turbine with doubly-fed induction generator**

The dfig with the power converter shown in Fig. 3.3 is a simple and highly controllable way to transform the mechanical energy from variable speed rotor to a fixed frequency electrical utility grid. Dfigs are popular because it can supply power at constant voltage and frequency.

## CHAPTER IV TRANSIENT MODEL OF A DFIG

### 4.1 Turbine modeling:-

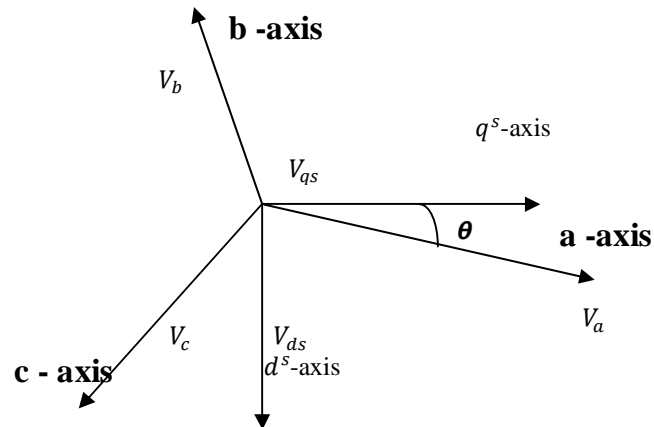
There are two ways in which we can divide the complete control strategies of the machine, one is the scalar control and the other one is the vector control. The limited use of scalar control makes way for the vector control. Although it is easy in executing the scalar control strategies, but the inherent coupling effects present give very slow response. This problem is overcome by the vector control. An Induction machine can be executed like a dc machines with the help of vector control strategy. Vector control is employed for achieving a decoupled control for both active and reactive powers. The base on which the vector control theory is based is d-q axis theory.

#### 4.1.1. d-q axis transformation (reference frame theory):-

Direct-quadrature zero conversion is a mathematical conversion employed to make easy the analysis of a three phase circuits, where three AC quantities are converted to two DC quantities. Various mathematical calculations are performed on the imaginary DC quantities and the AC quantities are again recovered by performing an inverse transformation on the DC quantities. It is very similar to Park's transformation, and it solves the problem of AC parameters that are varying with time. Employed to simplify the analysis of three phase circuits, where three AC quantities are converted to two DC quantities. Owing a smooth air-gap in the induction machine, the self-inductances of both the stator and rotor coil is constant, but the mutual inductances vary with the rotor movement with respect to that of the stator. Therefore the analysis of the induction machine in real time becomes very complex because of varying mutual inductances, as the voltage is nonlinear. Change of variables are therefore employed for the stator and rotor parameter to remove the effect of varying mutual inductances. This conversion leads to imaginary magnetically decoupled two phase machine. The orthogonally placed balanced windings are called d and q windings that can be considered as stationary or rotating relative to that of the stator. In the stationary reference frame, the ds and qs axes are fixed on the stator, with either ds or qs axis coinciding the a phase axis of the stator. In the rotating frame, the rotating d-q axes may be either fixed on the rotor or made to move with synchronous speed.

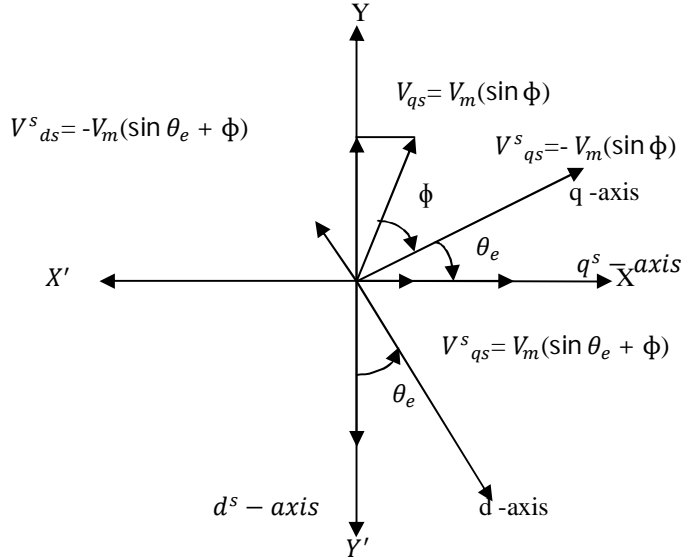
#### 4.2. Transformation from 3-phase stationary (a, b, c) to 2-phase stationary (ds, qs) axes:-

Here we are having three phases having a difference of 120 angle between each of them . This can also be seen in the figure .our purpose is the transformation of the 3 phases into Stationary (d-q) axis and then there transformation into rotating frame .



**Fig4.1:Transformation of 3 phases a-b-c to ds-qs axes**

#### 4.2.2 TRANSFORMATION FROM STATIONARY TO ROTATING AXES:



**Fig 4.2: Transformation of stationary axes to synchronously rotating frame axes**

Figure gives us the idea of transformation from stationary frame to that of rotating frame. It shows the method for the conversion of a three phase winding into a two phase fictitious winding.

The voltages of (d-q) into the terms of voltages of ds-qs:-

$$\begin{aligned} V_{qs} &= V_{qs}^s \cos \theta_e - V_{ds}^s \sin \theta_e \\ V_{ds} &= V_{qs}^s \sin \theta_e + V_{ds}^s \cos \theta_e \end{aligned}$$

Reverse method is done by resolving d-q voltage into ds-qs:-

$$\begin{aligned} V_{qs}^s &= V_{qs} \cos \theta_e + V_{ds} \sin \theta_e \\ V_{ds}^s &= V_{ds} \cos \theta_e - V_{qs} \sin \theta_e \end{aligned}$$

### 4.3 Mathematical modeling of Induction Generator:-

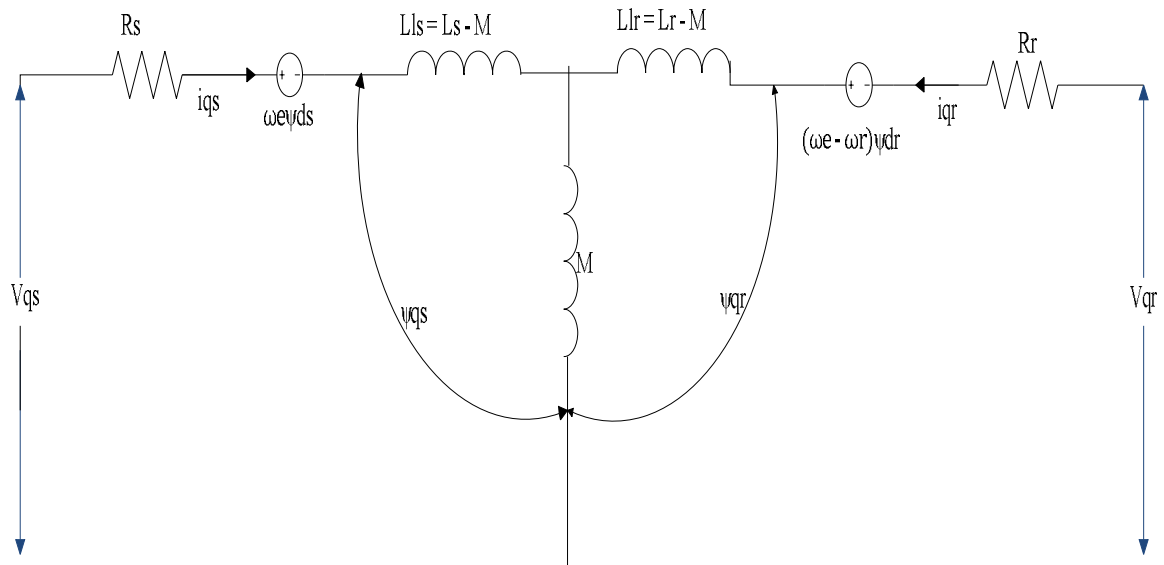
In this section the basic mathematical modeling of DFIG is described . From the previous section we got that the three phase parameters is represented in two phase parameters and vice versa using some basic rules. In this section the modeling of machine is explained by taking two phase parameters into the consideration. Although the basic concepts behind the DFIGS system are explained in short we can say the DFIG is a wound rotor type induction machine, it's stator consisting of stator frame, stator core, poly phase (3-phase) distributed windings , two end covers, bearings etc. The stator core is made by stacking of cylindrical steel lamination which is slotted along their inner periphery for covering the 3-phase winding. It's rotor consists of slots in the outer periphery to house the windings like stator. These machines work on the simple principle of the Electromagnetic Induction and the energy transfer takes place by the means of transformer action. So the machine can be represented like a Rotating transformer.

### 4.4 Modeling of DFIG in synchronously rotating frame:-

The equivalent circuit diagram of an induction machine is shown in picture below. In this picture the machine is represented to have two phase , it has been discussed before that a three phase machine can be represented by following some basic rules as a two phase machine. For the modeling of DFIG'S in the synchronously rotating frame of reference we have to represent the two phase of stator (ds-qs) and that of rotor (dr-qr) circuit variable in a synchronously rotating (d-q) frame of reference.

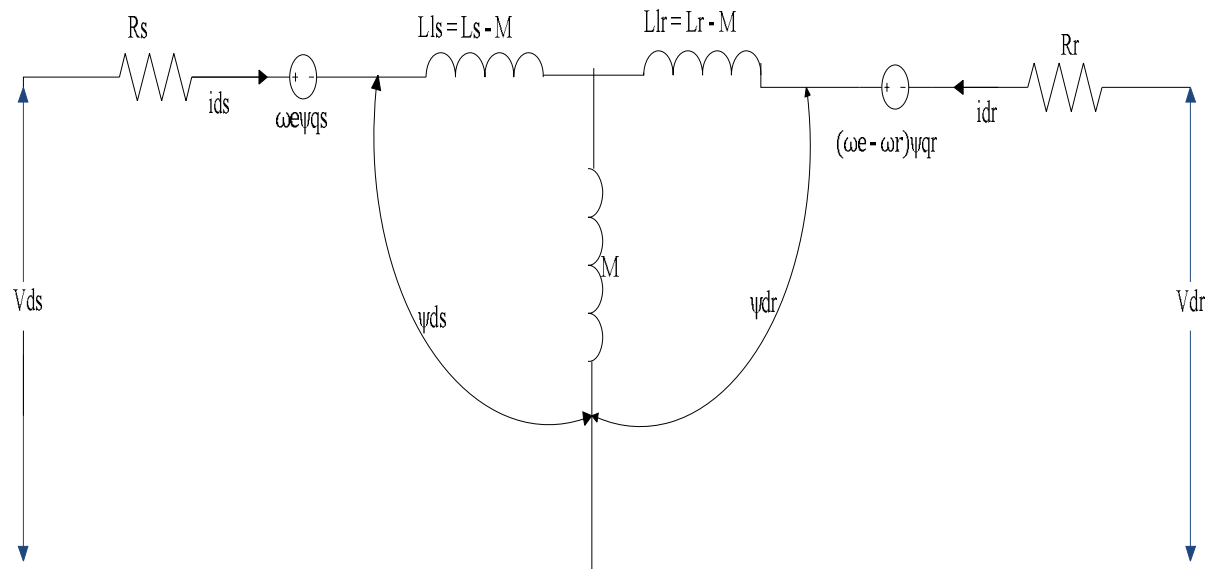
#### 4.5 d-q equivalent circuit (DFIG):-

##### 4.5.1 q-axis circuit:-



**Fig 4.3: q-axis equivalent circuit of DFIG in synchronous (d-q) frame**

##### 4.5.2 d-axis circuit:-



**Fig 4.4: d-axis equivalent circuit of DFIG in synchronous (d-q) frame**

Stator Voltage:-

$$V_{ds} = R_s i_{ds} + \omega_s \phi_{qs} \quad (10)$$

$$V_{qs} = R_s i_{qs} - \omega_s \phi_{ds} \quad (11)$$

Rotor voltage:-

$$V_{dr} = R_r i_{dr} - s \omega_s \phi_{qr} + \frac{d\phi_{dr}}{dt} \quad (12)$$

$$V_{qr} = R_r i_{qr} + s \omega_s \phi_{dr} + \frac{d\phi_{qr}}{dt} \quad (13)$$

Flux linkage:-

$$\phi_{ds} = l_s i_{ds} + l_m i_{dr} \quad (14)$$

$$\phi_{qs} = l_s i_{qs} + l_m i_{qr} \quad (15)$$

$$\phi_{dr} = l_s i_{dr} + l_m i_{ds} \quad (16)$$

$$\phi_{qr} = l_s i_{qr} + l_m i_{qs} \quad (17)$$

In these equations  $R_s$ ,  $R_r$ ,  $l_s$  and  $l_r$  are respectively the resistances and inductances of the stator and rotor windings,  $l_m$  is the main inductance and  $\omega = P \cdot \Omega_{mec}$  is the rotor speed.  $V_{ds}, V_{qs}, V_{dr}, V_{qr}, i_{ds}, i_{qs}, i_{dr}, i_{qr}, \phi_{ds}, \phi_{qs}, \phi_{dr}, \phi_{qr}$  are the direct and quadrature components of the space phasors of the stator and rotor voltages, currents and flux respectively.

The active and reactive powers at the stator are defined as:

$$P_s = V_{ds} i_{ds} + V_{qs} i_{qs} \quad (18)$$

$$Q_s = V_{qs} i_{ds} - V_{ds} i_{qs} \quad (19)$$

The active and reactive powers at the rotor are defined as:

$$P_r = V_{dr} i_{dr} + V_{qr} i_{qr} \quad (20)$$

$$Q_r = V_{qr} i_{dr} - V_{dr} i_{qr} \quad (21)$$

The electromagnetic torque is expressed as:-

$$T_e = \frac{3P}{2} (\phi_{ds} i_{qs} - \phi_{qs} i_{ds}) \quad (22)$$



## CHAPTER V SIMULATION:-

### 5.1 PITCH CONTROL OF WIND TURBINE:

Explanation:-

$$P_m = 0.5 C_p(\lambda, \beta) \rho A V_w^3$$

Where

$P_m$  is mech. Output power

$(C_p)$  is power coefficient

$\rho$  represents air density

$A$  represents swept area

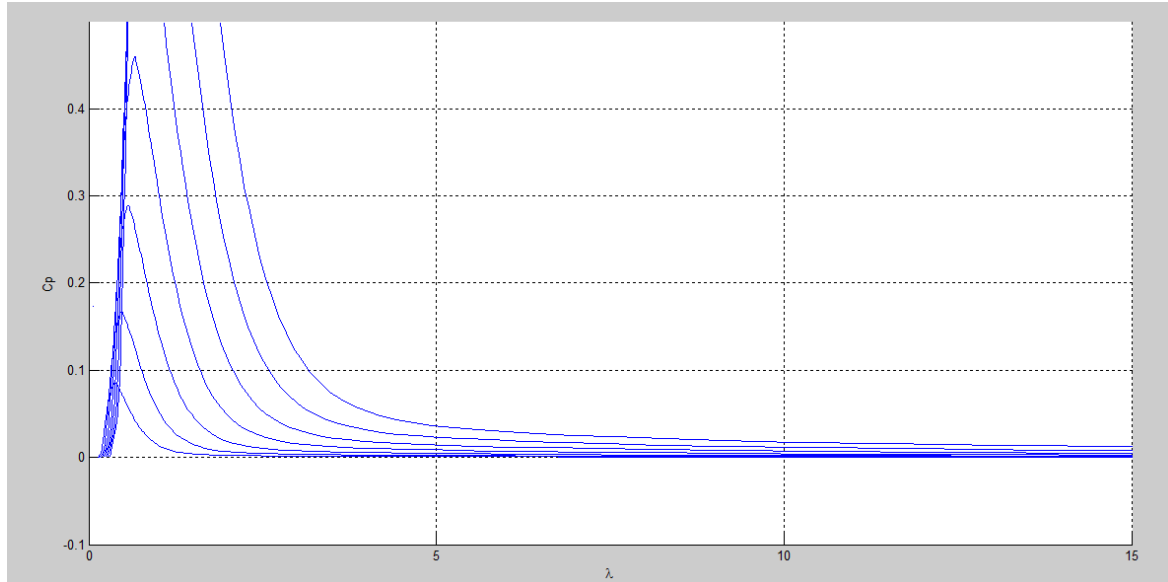
$V_w$  means wind speed in (m/s)

$\lambda$  represents the value of tsr

$\beta$  is pitch angle

#### PROGRAM:

```
l=0.01:0.1:15;
s1=0.5165;
s2=121;
s3=0.3;
s4=6;
s5=24;
s6=0.0069;
pitch=0:5:25;
Fori=1:6
For p=1:length(l);
X (p) =1/(l(p)+0.08*pitch(i))-0.035/(pitch(i)^3+1);
Y (p) =s1*(s2*A(p)-s3*pitch(i)-s4)*exp(-s5*A(p))+s6*l(p);
End
Plot (X(p),Y(p));
Hold on;
End
Axis ([0 20 -0.1 0.8]);
xlabel('\lambda'),ylabel('Cp');
```



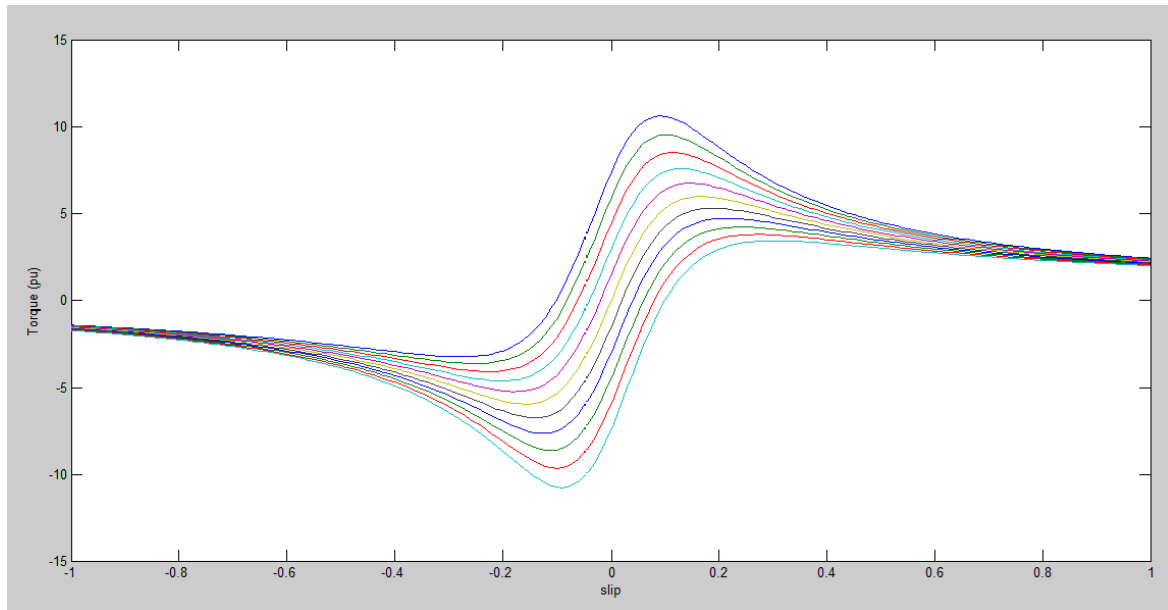
**Fig: 5.1 Power coefficients versus tip speed ratio**

## 5.2 TORQUE SLIP CHARACTERISTIC:-

```

Xs=0.0145;
Xr=0.0085;
Rs=0.00060;
Rr=0.00340;
Vs=0.6;
Vr=-0.05:0.01:0.05;
For j=1:12
p=-1:0.01:1;
For k=1:201
Q(j,k)=(s(k)*Vs^2-Vs*Vr(j))*(p(k)*Rs+Rr)/((p(j)*Rs+Rr)^2+p(k)^2*(Xs+Xr)^2);
End;
Plot(p,Q);
End;
Axis ([-1,1,-15,15])
xlabel('slip'),ylabel('Torque (p.u.)');

```



**Fig: 5.2 Torque-slip characteristic**

### 5.3 MECHANICAL CHARACTERISTICS

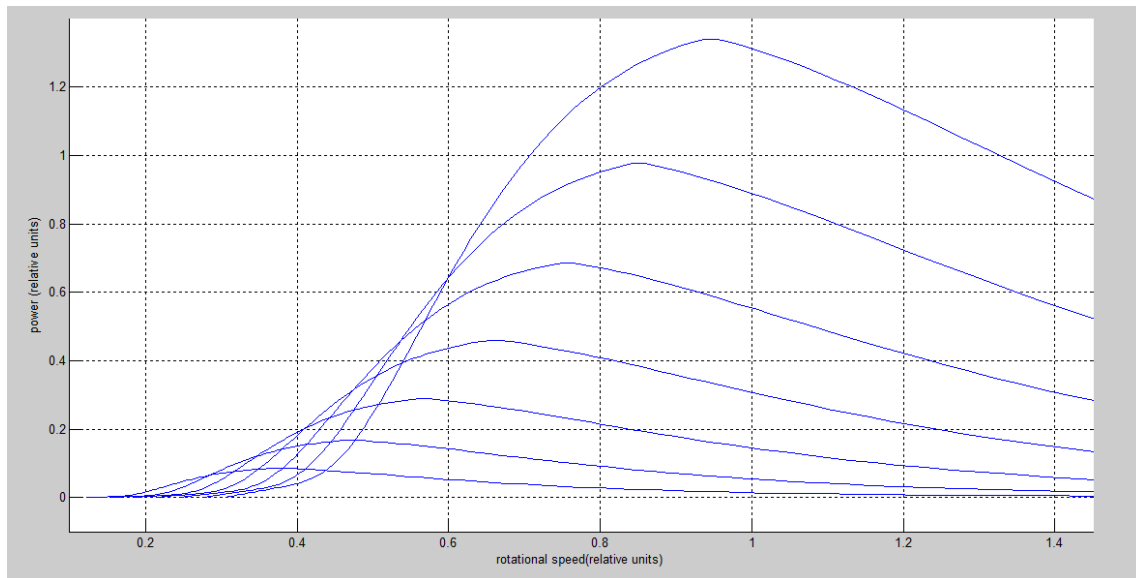
% mech\_characteristic.m  
 % numerical simulation of the  $C_p$  of the wind turbine as a function of the tip speed ratio (tsr)

```
s1=0.5165; s2=121; s3=0.3; s4=6; s5=24; s6=0.0069; R0=1.30;
W=40; X=pi*D^2/4;
l=0.01:0.1:15;
s=0;
V=[8,10,12,14,16,18,20];
For c=1:length(V)
For d=1:length(l);
XI (d)=1/(L(p))-0.035;
YP (d)=s1*(s2*XI(p)-s4)*exp(-s5*XI(p))+s6*l(p);
b (c,d)=(V(k)^3)*YP(p)*R0*X/2;
m (c,d)=(60/(pi*W))*XI(d)*V(c);
End;
Hold on;
End;
N=max (P(6,:)); n=max(N); P=P/m; m1=length(l); m2=length(V);
```

```

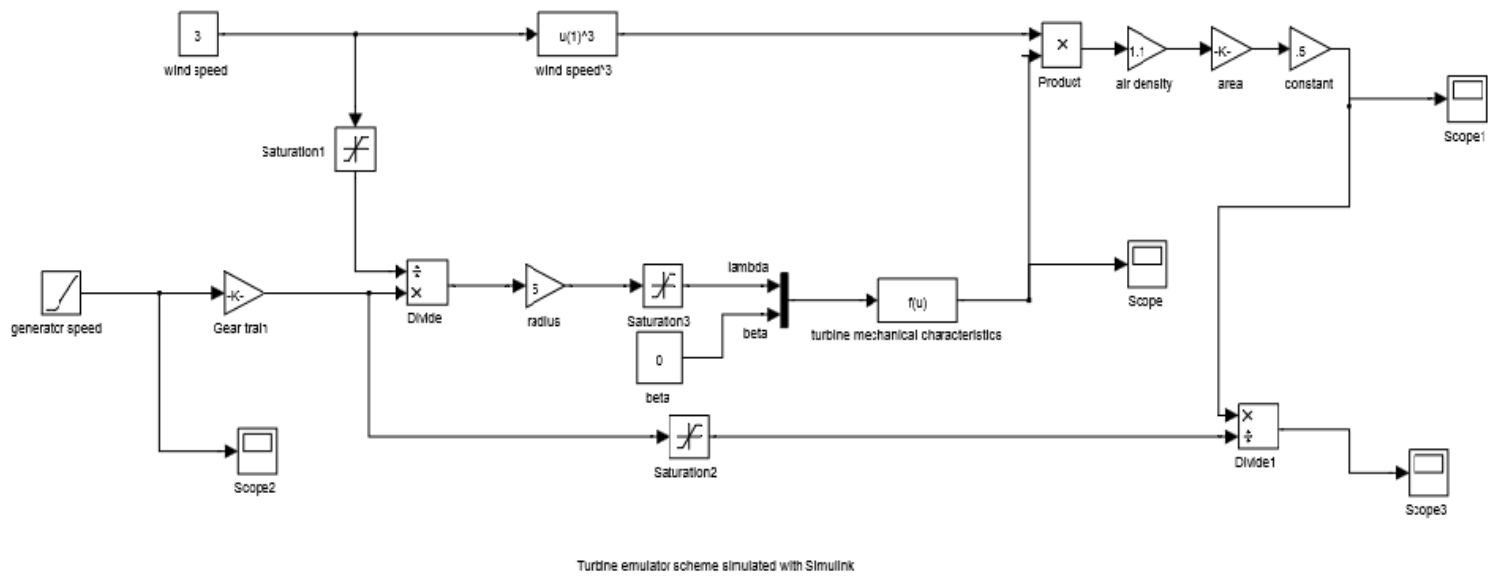
For u=1:m1;
P(:,m1-u+1)=d(:,u);
End;
PR=P;
For o=1:m2;
Plot (m(o,:), PR(o,:)); hold on
End;
Grid; axis([0.1,1.45,-0.1,1.4]);
xlabel('rotational speed(relative unit)'),ylabel('power (relative unit)');

```



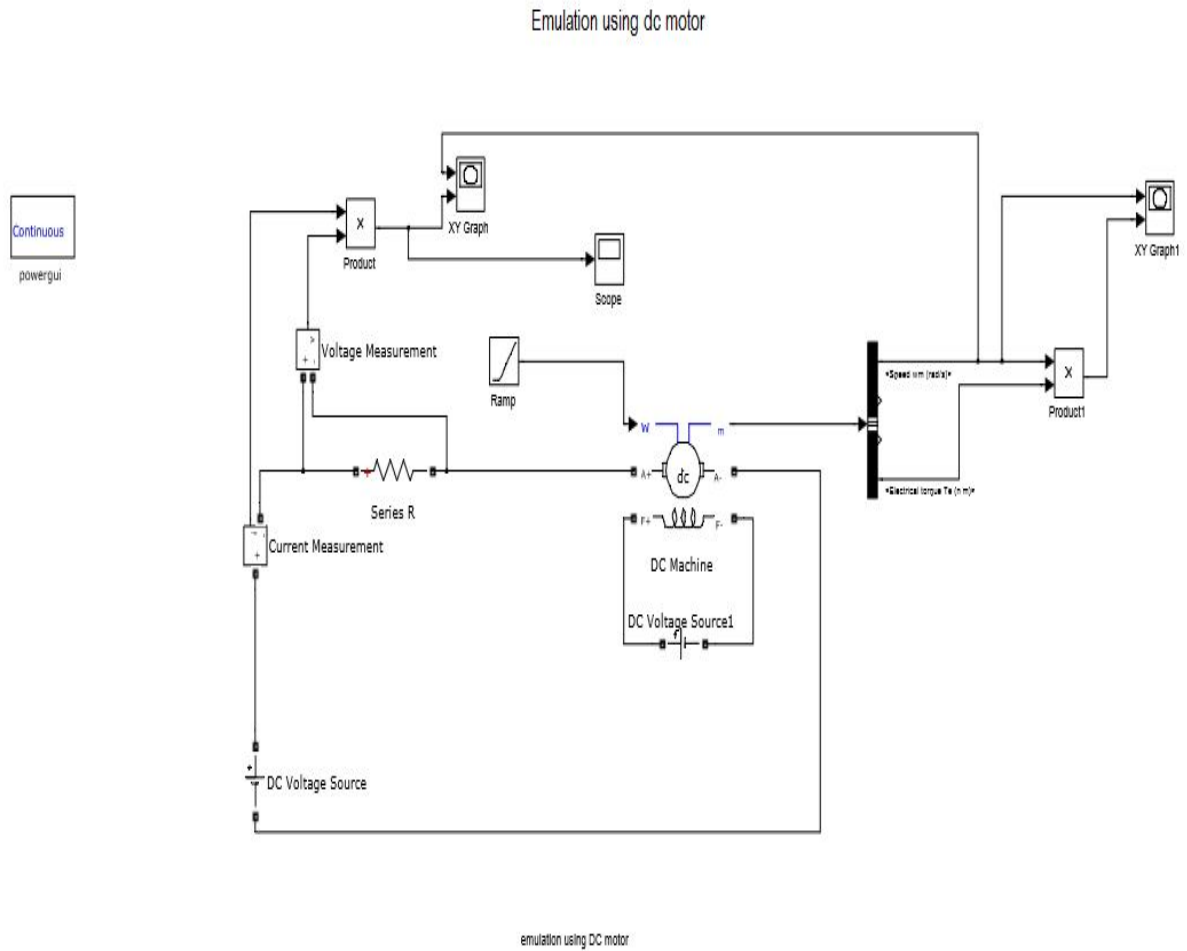
**Fig: 5.3 Wind turbine output power vs. rotational speed, with wind speed as parameter**

## 5.4 TURBINE EMULATOR SCHEME SIMULATED WITH SIMULINK

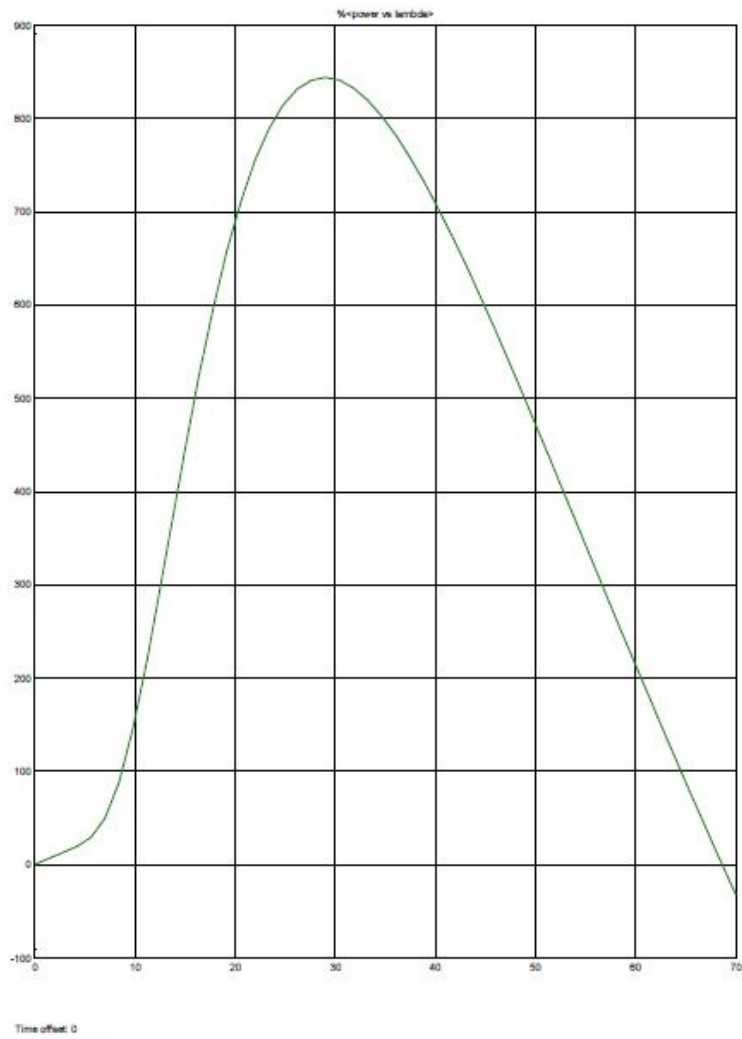


**Fig: 5.4 Turbine emulator**

## 5.5 EMULATION USING DC MOTOR



**Fig: 5.5 Turbine emulator using dc motor**



**Fig: 5.6 Power versus tip speed ratio**

## 5.6 DYNAMIC MODEL OF DFIG

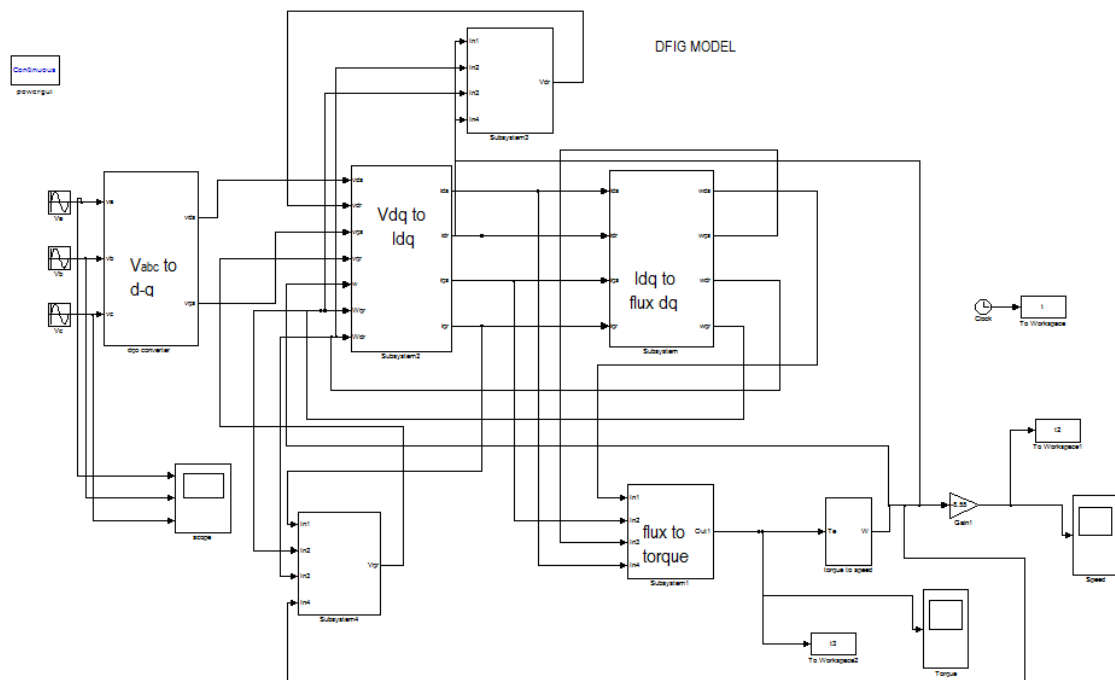


Fig: 5.7 DFIG dynamic models

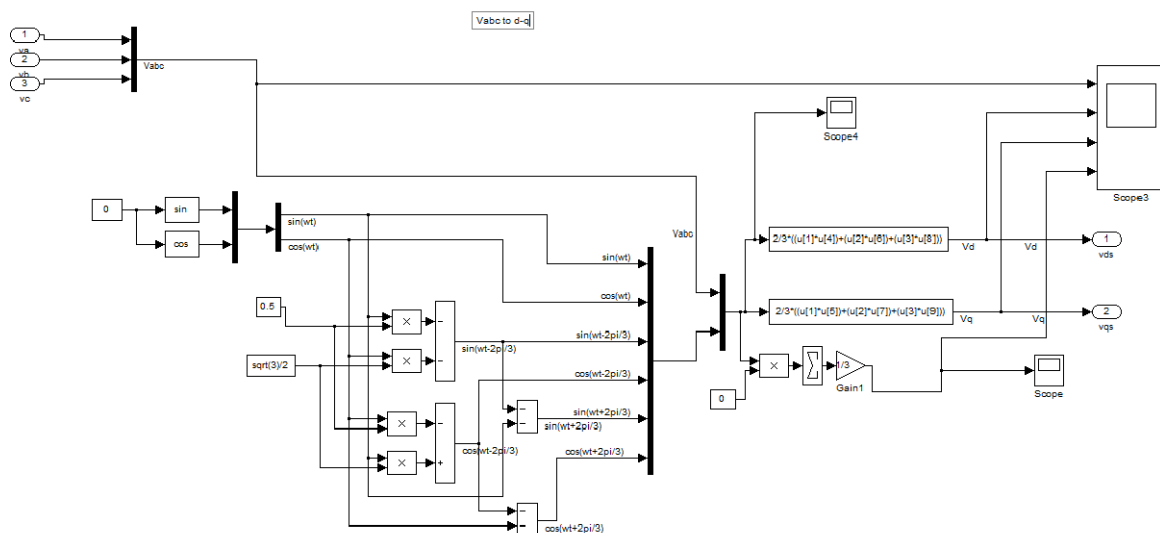
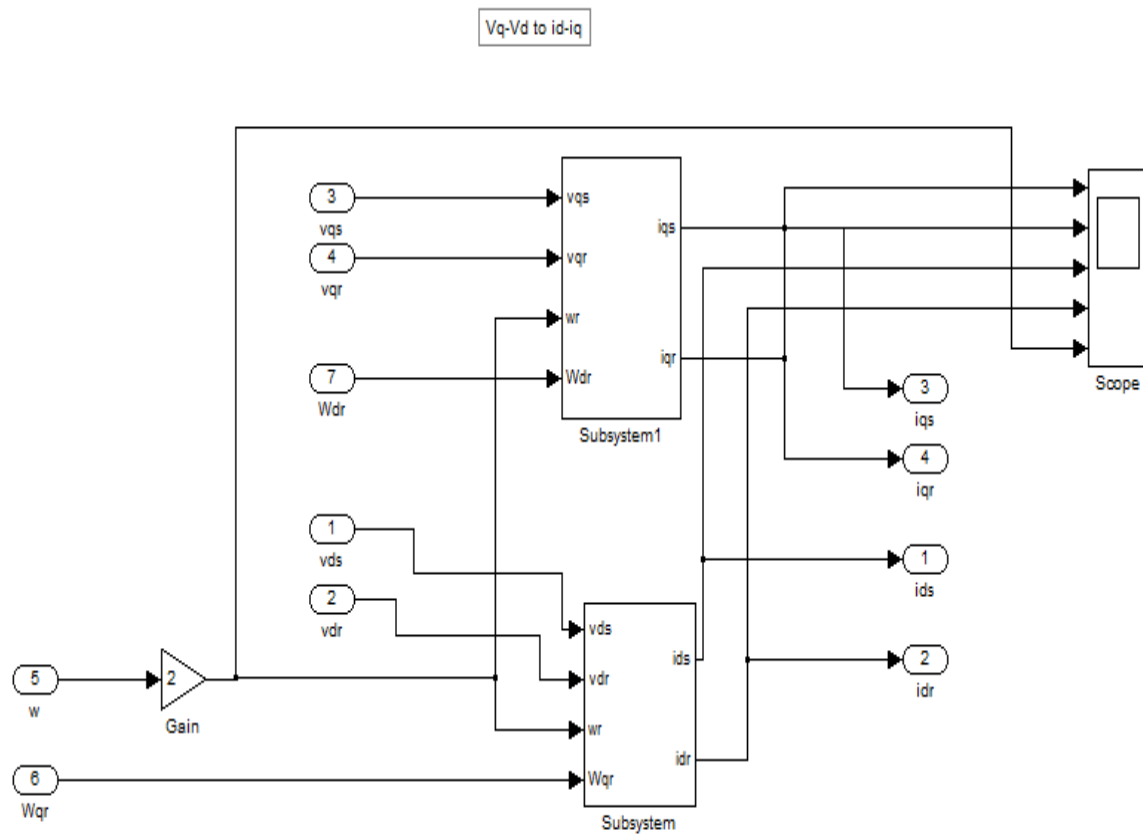
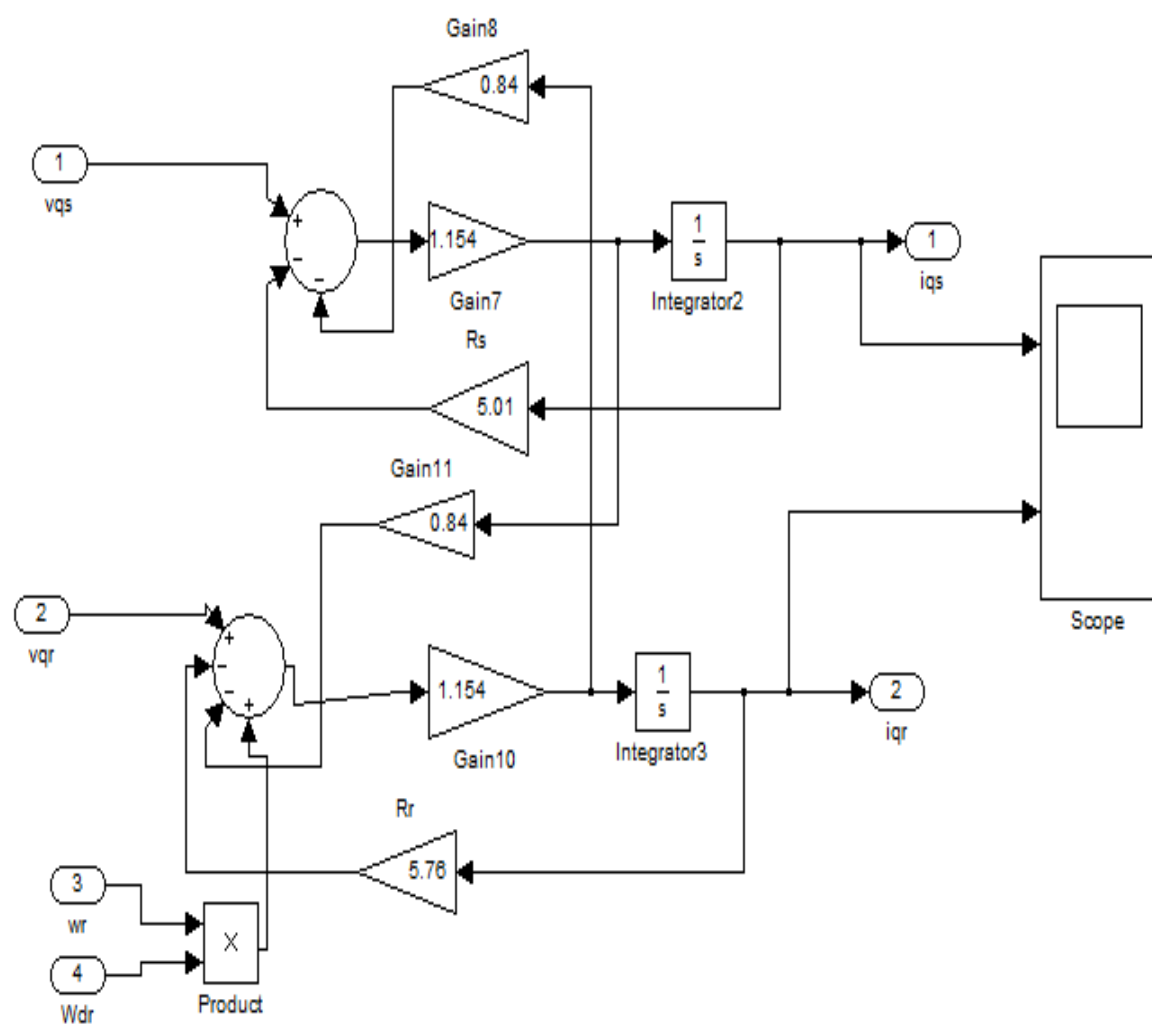


Fig5.8 3-phase to 2-phase d-q model



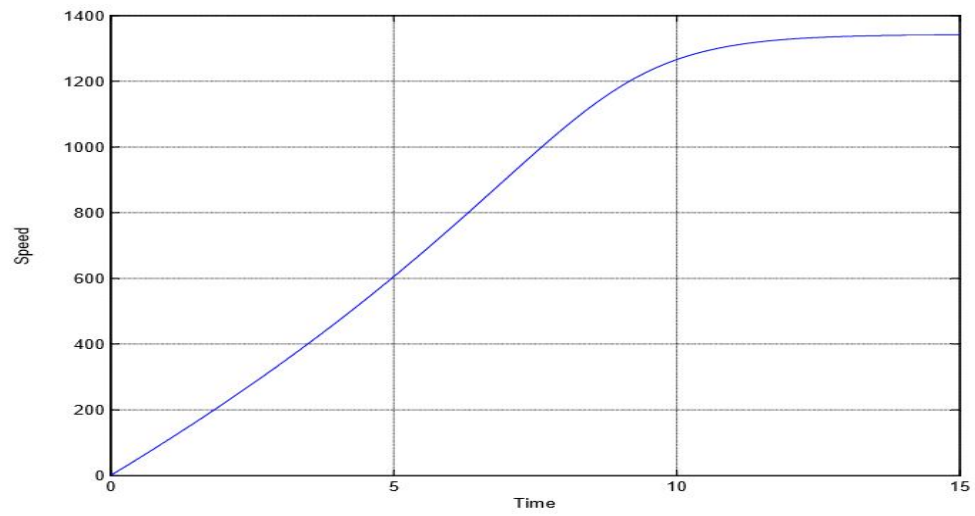


**Fig5.9Vdq to idq conversion**

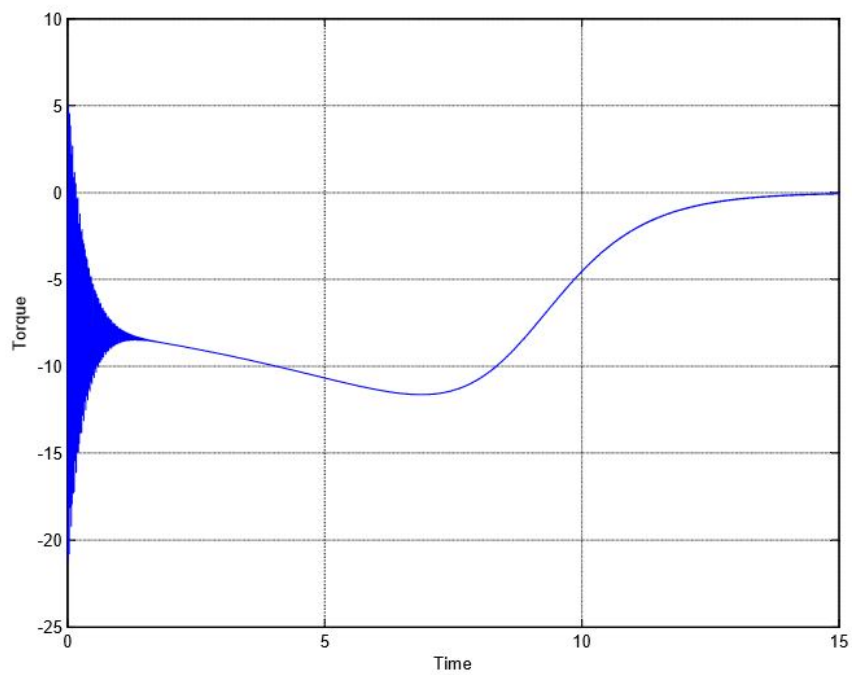


**Fig5.10**  $v_{dq}$  to  $i_{dq}$  conversion

## SIMULATION RESULTS

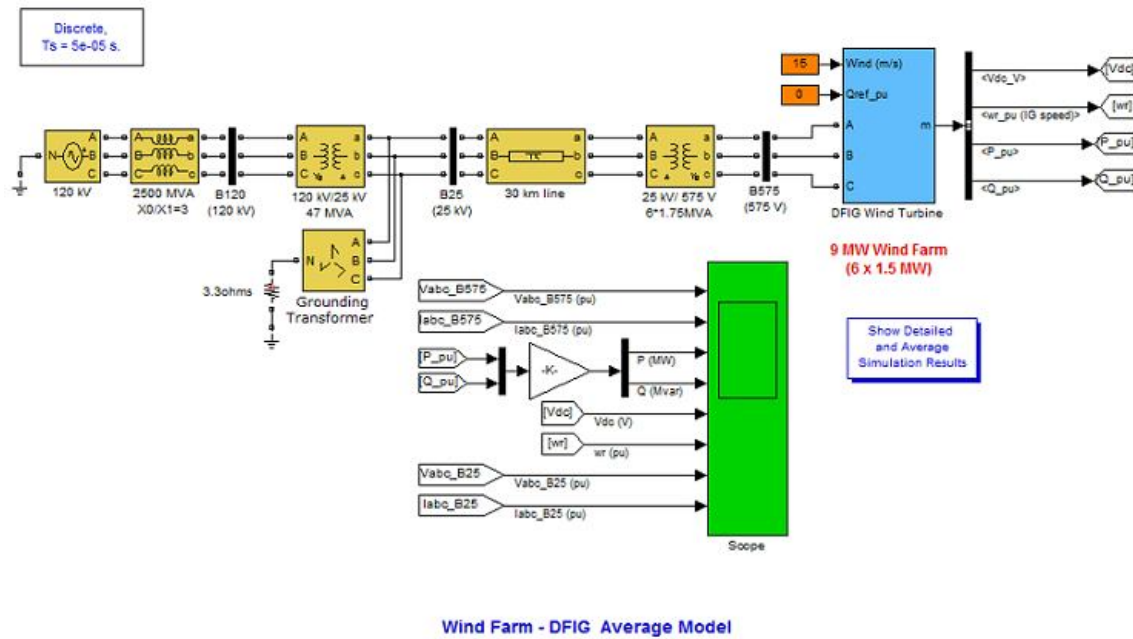


**5.11 Speed vs Time**



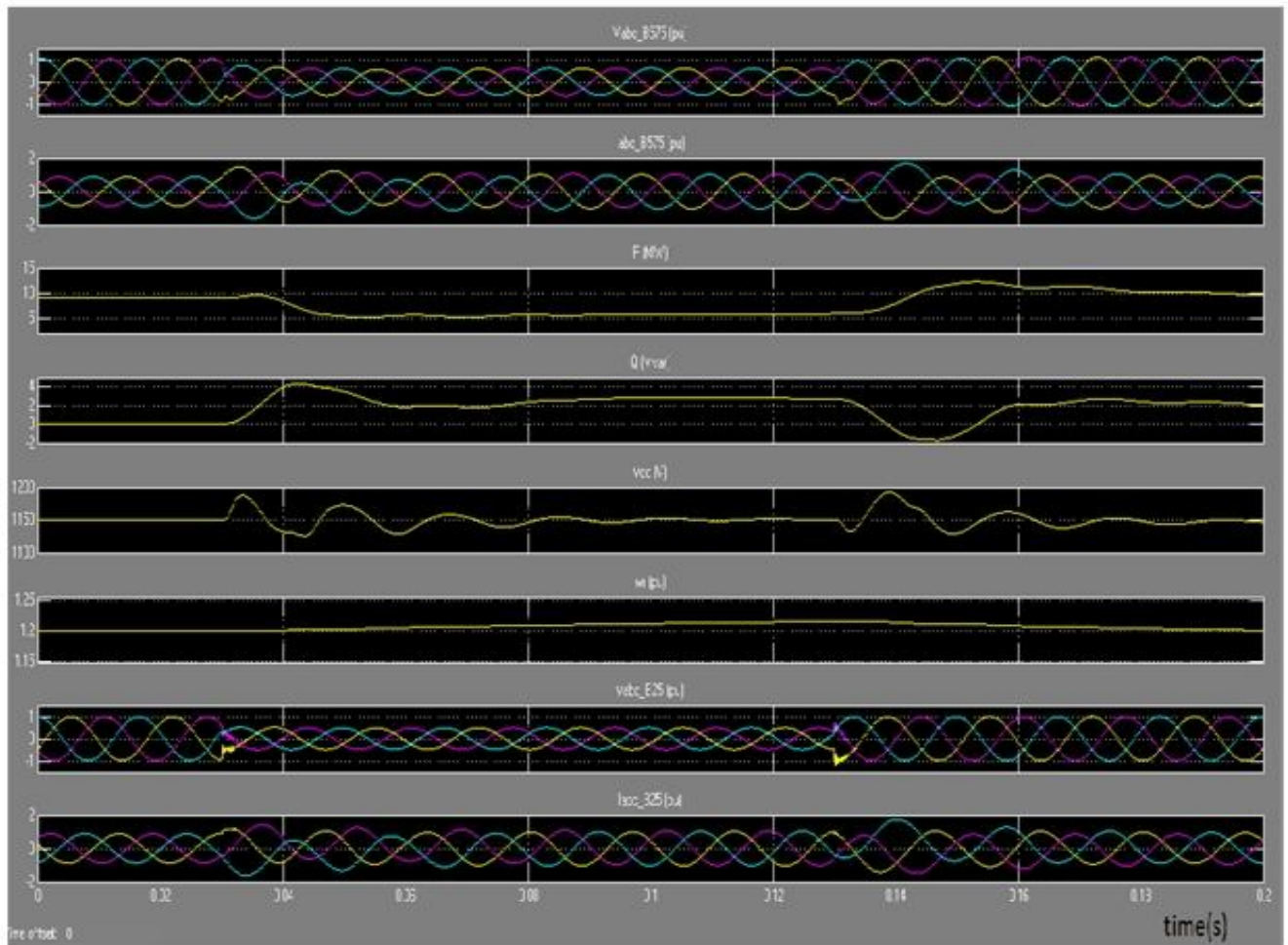
**5.12 Torque vs Time**

### 5.3 STUDY OF WIND TURBINE AVERAGE MODEL



**Fig: 5.13 Wind farm DFIG Average Model**

## RESULTS OF DFIG AVERAGE MODEL



5.14 Output of DFIG average model

## CONCLUSION:-

The theory of wind turbine was analyzed in detail leading to the modeling in the synchronous frame of reference employing a doubly fed induction generator. dfig modeling was done and equations were simulated in matlabsimulink .The wind turbine modeling has been done using Simulink, various curves like  $(C_P-\lambda)$ ,  $(C_Q-\lambda)$  was observed

## FUTURE WORK:-

Since future power generation depends on renewable energy so there is a lot of research work to be done on wind energy conversion systems .in this paper in future any body can work on the control part of the model by designing voltage and current controllers .

With the development of modern type controllers stability and dynamic characteristics of an induction generator connected to grid can be improved.

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## APPENDIX

### SPECIFICATION AND RATING OF DFIG

SPECIFICATION	RATING
STATOR VOLTAGE	575V
RATED POWER	9MW
ROTOR RESISTANCE	0.016 $\Omega$
STATOR RESISTANCE	0.023 $\Omega$
ROTOR INDUCTANCE	0.16H
STATOR INDUCTANCE	0.18H
WIND SPEED AT NOMINAL SPEED ANDAT CP MAX	11 m/s
MUTUAL INDUCTANCE	2.9H
INERTIA CONSTANT	0.685



